RHYTHM, TIME AND NUMBER.

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The experimental researches on rhythm of Bolton, Meumann, Ebhardt and others have familiarized us with the idea of interdependence between the factors of time, intensity, number and position in the rhythmical sequence. They have corrected our apprehension of the nature of the absolute intervals which enter as constituents into the simple rhythm group, and have shown these to be no fixed units, but variables whose magnitude fluctuates with every change in the index of variation in the limiting stimuli. They have made known to us that the time-relations of the sounds which compose music and verse are neither simple nor constant, that the proportions presented by successive notes or syllables are vastly more complex than the score or the metrical scheme indicates, and that their ratios vary with every change of emphasis, expression and mood in the speaker.

The plastic character of their elements commonly escapes our notice in the rhythms of speech and song. The changes of which we are conscious are those of verbal meaning, interpretation and emotional tone. It requires an attitude of artificially discriminative attention to discover even the variations in stress and tonal quality which are involved in the production of such effects upon the hearer, while the concomitant changes of temporal relations in emphasized words, in sustained and slurred notes, in significant and insignificant pauses, cannot be brought to light by any device of introspective observation. Every accentuation lengthens the sound upon which it falls, and every composition of an auditory series into a rhythmical unit transforms the apparent magnitude of the intervals which separate it from preceding and following groups. These expansions and contractions of duration vary in extent with the intensity of the sounds which support them, and in virtue of this constant functional relation they uniformly escape notice.

The process of rhythmical integration must therefore be taken into account as an important factor in every consideration of the phenomena of the time-sense and the means by which we apprehend and estimate series of successive impressions. Since our discrimination of durations is always of intevals bounded by limiting sensations, there is made possible the appearance

of a process of rhythmical accompaniment wherever certain temporal conditions obtain among the successive stimuli of the series. If the latter thus originate a rhythmical mode of apprehension there will at once be introduced specific errors of estimation which will transform the whole nature of the intervals to be compared. The process of sensory rhythmization must therefore be considered first in its functional relation to general nature of the time-sense, and, if it be an indispensable factor in the estimation of temporal quantities, the effects of its various specific forms must further be discriminated in the analysis of the conditions under which appreciation of time-relations takes place, and of the factors which make for accuracy and inaccuracy in the process.

The relations of rhythmization to the time-sense are inevitably misconstrued by the observer who depends upon introspection for his results, and to this source is to be attributed the error of those psychologists who describe the sense of time as attaining its greatest refinement in the apprehension of rhythmical series. Thus Sully says, (Outlines of Psychology, Pt. III, p. 172, Am. Ed.). "It is, however, in the ryhthmic successions of verse and music that the ear's appreciation of time-relations shows itself at its best. The essential element in this experience is regular recurrence after a definite interval, or periodicity. Here an accurate measurement of time-interval becomes essential." The results of experimental observation contradict such an idea. There is present in all musical and poetical perception a characteristic transformation of time-values which makes the immediate comparison of successive intervals impossible. The estimation of absolute duration in rhythm depends finally upon factors which are themselves subject to variation. It is not the accurate measurement of successive intervals of time which is essential in rhythm, but the maintenance of proportionate relations among successive groups.

This preservation of time-analogies depends upon the capacity for a very nice reproduction of a succession of experiences of strain. Accurate estimation of time in music obtains only between intervals whose durations measure like strain experiences. Intervals bounded in the same way, or having similar functions in the musical sequence, are perceived and reproduced with great accuracy indeed; but no dynamically unlike intervals can ever be justly estimated as time-extents. Change the position of the given interval in the series of which it forms a part, alter its function in the rhythm group, increase or decrease the accentuation which its limiting sensations receive, and its psychological duration is immediately transformed beyond recognition. The same absolute interval has as many time-values

as there are varying structural relations in the rhythmical form of the music or verse in which it appears.

It is just when the succession of intervals is not part of a rhythmical sequence that accurate comparison of their values becomes possible. To this end each interval must have an independent existence; the moment two become members of a common structural unit the possibility of immediately comparing their extents disappears. The latter process is strictly one of automization, and characterizes all perception and production of rhythmical quantities. I think Meumann has seized only half the truth when he says that an estimation of the time of movement in beating verse exists so long as the movements are not automized; and that when automized the periods are maintained without being estimated. The former relation is a condition which is never realized. So long as the successive beats and intervals are not automized,—so long, that is, as the successive intervals do not coalesce into groups which themselves replace the single beats as units, no rhythmic perception arises, and no scansion or beating of time is possible. The effect of rhythmization in thus masking the absolute values of the time intervals involved was noted by Mach in 1866. He remarks (Untersuch. u. d. Zeitsinn d. Ohres, p. 181) that when iambic series are frequently repeated in the same direction the hearer ceases to discriminate the longer from the shorter interval. Similarly Hall and Jastrow write in their Studies of Rhythm (Mind, Vol. XI, p. 61) that "after the series had been heard two or even three times, no impression of the relative length of the middle interval (of three) would often exist, and only after hearing the fourth and last would the judgment incline to the plus or minus side." The work of practically every experimentalist since these early observations were made has incorporated the same results.

The critical comparison of duration in successive groups of elements in a rhythmical sequence likewise disappears as an immediate experience. Such groups occupy objectively the same time-extents only when,—and because—they have the same functional relations in the verse and the stanza. The moment a higher synthesis appears and two formally like groups assume relations of super- and sub-ordination to one another,—as when one receives a major, the other a minor accent in a common higher group—the perception of their absolute time-values becomes impossible. On the other hand, as in the case of primary rhythmical quantities, the attempt to observe the larger structures of the passage and the stanza, for the purpose of comparing their durations, is instantly destructive of the rhythmical impression.

It is practically beyond question that every motor accompani-

ment of a series of regularly recurrent sensations tends to interfere with the proper estimation of the time-values of their intervals by thus becoming automatic. Müller and Schumann report that they have found such estimations most accurate when the limiting sensations are passively listened to; and that the ability to make exact comparisons is interfered with when motor activity is introduced. Ebhardt ascribes this interference to a displacement of the function of judgment by the process of motor activity which occupies the period in which the comparison must take place. The displacement of discrimination by another process is important in proportion as the motor adaptation makes large demands upon the process of attention, but it plays a diminishing part as the systems of reactions become more and more automized. It is a familiar observation that mechanized series of this kind may exist without any perceptible drain upon attention, and it seems difficult, at first blush, to account for the interference which their establishment arouses.

Automization of any process means characteristically an increased regularity and stability in its relations; while the process controlled by selective consciousness is as typically marked by variability in its form and instability in its internal relations. The intervals between automized movements are certainly more uniform than those between reactions which are consciously supervised. If the process involved only the automization of a series of concomitant movements synchronous with the series of sensations, and the perception of departures from uniformity in the occurrence of this succession, then we should expect the process of time-estimation to be facilitated instead of obstructed by the introduction of the factor of movement.

The interference, however, is not to be doubted. Its source is to be looked for in either (or both) of two factors. The process of automization of movement takes place under certain laws of natural rhythm which are characteristic of the individual but which probably differ but slightly from subject to subject. Thus Stevens, in a series of experiments on the time-sense (Mind, Vol. XI, p. 393), required his subjects to accompany the beats of a metronome by synchronous movements, and to continue the series at the same rate after the instrument had been stopped. The two series agreed only when intervals of a certain magnitude occurred between adjacent beats. In the one case there was coincidence, in the other interference with the natural period of the subjective rhythm, which in these experiments varied from 53σ to 87σ. In Scripture's investigation "the intervals chosen were, on an average, 92, 94, 152, 156, 160, and 180σ." If the intervals to be compared are in-

commensurable with the period of this bodily rhythm, the lack of correspondence between their phases exerts a disturbing instead of a facilitating effect upon the process of time estimation. Münsterberg, in his work on the comparative estimation of successive durations, has emphasized the fact that there is no function of consciousness which can be called a special time-sense. Subjective standards of measurement are uniformly dependent upon physiologically conditioned changes, in sense-organ, muscle, respiration and the like. For periods of short duration rhythmical variations in the tension of the sense-organs afford the basis of our judgments; in the immediate apprehension of longer periods our estimates are chiefly determined by the functional rhythms of respiration. Rise and fall of tension, forming a completed wave of sensation, accompany each act of inspiration and expiration. According as the impressions coincide or fail to coincide with like phases of this process, the duration of their separating intervals will be judged clearly or confusedly; and according as they endure through equal or unequal multiples of this unit will they be judged to be equivalent or non-equivalent.

But secondly, all beating of time, whether or not consciously intended to embody a specific rhythm form, tends to fall into secondary rhythms by which the objective values of the intervals to be compared are destroyed as elements of presentation. Neither the centrally determined series of reactions nor that which seeks to reproduce an absolutely uniform succession of sensory impressions is free from rhythmic phases. The types of differentiation which such systems of reactions present affect both the intensity of its elements and their temporal relations. The definition and extent of such free rhythmization depend upon the absolute rate of succession among the stimuli involved, upon the quality of these stimuli, and upon the nature of the synchronous attention process. Its occurrence makes the process of time-comparison difficult, insecure and in any strict sense impossible. Attention must be renewed at every act if the series is not thus to be automized and fall into accentual groups. The moment inattention ensues, or the series is taken as a whole or in groups, the opposing phases of rhythm appear. Either, therefore, the process of motor adjustment requires attention and the judgment is displaced, or it is automized and the material of judgment is transformed in value. In both cases the accurate discrimination of duration will be seriously interfered with.

The phenomena of mechanized motor impulses seems thus to be essentially antagonistic to the process of time-discrimination. On the contrary, it is upon the phases of such rhythmical processes, in the last analysis, that not only forms of æsthetic

apprehension but the sense of time itself depends. Contradiction appears and the capacity for correct discrimination is destroyed only when the intervals to be compared are bounded by dynamically unlike limits. The reproduction through a motor process of the intervals to be compared, which is spontaneously established in the presence of exciting stimuli, is indispensable to the function of temporal judgment. Horwicz calls rhythm the only measure of time, and ventures the assertion that a being whose experience did not manifest periodicity could gain no conception of its nature. Time does not make rhythm, but rhythm time.

Such phases of generally rhythmical change may belong to either of two categories, namely sensation and movement; and theorists of the time-sense have severally based their derivation of its phenomena upon each of these. Thus Lipps connects our judgments of time with the process of fading which the course of sensations manifests, qualitative differences in the elements of consciousness being translated into concepts of temporal order and value. But such experiences are qualitatively rhythmical only, and give no adequate basis for time comparison; for the series of external stimulations is without any sufficient principle of periodicity, to some form of which the phenomena of the time-sense must finally be referred.

Within the organism itself such rhythmical changes are abundant, and to these facts the majority of observers have turned for an explanation of temporal judgments. There are certain constant conditions of feeling, as Waitz points out, which characteristically accompany these processes of change in sensation or other conscious content,—straining of the attention, feelings of expectation and surprise, of impatience and tediousness,—and it is to these, not to the disorderly palimpsest of fading sensations, that we most hopefully look for an understanding of the facts of time-estimation. "This theory of temporal signs," writes George C. Robertson (referring to Dr. Ward's view of movements of attention as temporal signs), "may fairly be regarded as the most interesting contribution to the subject since Herbart."

Wundt likewise connects the process of accurate time-estimation with primitive types of rhythm in the bodily activities. He points out the fact that the interval of time of which we have the clearest grasp as an object of sensible intuition, judged by the degree of sensitiveness to variations in its extent, is just that which Weber had observed to be the average time occupied by the leg-swing in rapid walking. We can estimate such periods best because the laws of our physical organism make it most easy to mark time to them by some form of organic adjustment or motor reaction. The value of this period is

variously given by different experimental observers, as follows: Mach, 0.375 sec.; Stevens, 0.71 sec.; Kollert, 0.755 sec.; Mehner, 2.15 secs.; Vierordt, 3-3.5 secs. Of these only two (0.71 and 0.755) present even a moderate approximation to each other; but through the whole series runs a fairly defined periodicity. The unit of this rhythm is not the value ordinarily assigned to the period of most accurate estimation,—three-quarters of a second—but about one-half of this. All the subsequent members of the series, if we include Vierordt's results, which present rather the indifference-point at which the tendencies to over- and under-estimation disappear, embody this primary period. It seems probable, therefore, that the duration most accurately estimated is one including both phases of a complete rhythmical change.

As to the special processess of adjustment involved in the apprehension of temporal quantities there is probably no last word to be said, in so far as the phenomena of time-estimation are not necessarily correlated with any one type of organic change. Horwicz considers that all the rhythmical functions of the body serve this purpose in turn,—respiration, pulse, movements of the legs, jaws, etc., and the alternations in larger rhythms of hunger, sleep, work and the like. The immediate apprehension of time is, however, to be understood only in connection with rhythmical changes in the organism of imcomparably shorter period than those of sleep and waking, labor and rest. Of these shorter rhythms most stress has been laid upon respiration and the beating of the heart. Leumann compared the natural rates of reading verse in different persons with the normal periods of their pulses, and found that one with a pulse of eighty-five beats per minute read one hundred and seven metrical feet in a minute, while one with a pulse of ninety-eight read at the rate of one hundred and twenty-nine feet. He found also that the pulse of a single subject changed from seventy-seven, when scanning one hundred and thirteen feet per minute, to eighty-three when scanning one hundred and forty feet. With changes of this type Leumann connects the phenomena of attention waves, and what James calls "the rhythmical sharpening of our time-sense."

Mach considers the time-sense to be as special as that of vision. He surmises that its organ is to be found in the mechanism of the ear; that processes of accommodation are set up by sensations, varying with their intensity, duration, etc.; and that from the phases of such adaptation has originated the apprehension of succession and duration, analogous with the perception of distance and perspective by the eye. It is questionable if the ear is an analogue of the eye in this regard. The elements of visual space-perception are derivative in their

nature, and represent certain primary successions of motor sensations involved in the exploration of the external world. But this set of secondary perceptions is exceedingly well organized and independent. In various animal types it presents a system of sensori-motor adaptations organized in advance of individual experience and depending upon the inherited assimilative formula of the organism itself. In human perception all pronounced motor interpretation has fallen into abeyance and we depend in a very complete fashion upon immediate visual sensation for our representation of space-relations.

If we assume the ear to be capable of analogously becoming the organ of time-perception, it is still only as a secondary mechanism the changes in which are representative of certain primary experiences of tension and release. Such substitutionary agencies arise only in virtue of the greater sensibility or control of special organs, and development by no means exists here in any such degree as characterizes visual space perception. Introspection reveals the existence at every point of wide-spread rhythmical tensions and releases in the organism, as the accompaniment of all attentive time-estimation. The inhibition of these, or the contravention of their phases, means the mutilation of our time-perception. Whatever may be the possible future development of auditory function in the apprehension of time-values, the process is still intimately bound up with these primary sensations of tension and movement themselves.

In so far as the element of organic adjustment is concerned in the appearance of time-values it must be recognized that this process cannot be localized in a single mechanism, such as the ear, without presupposing an evolution for which there is little empirical justification. The estimation of time is in no way restricted to auditory experience; one judges as readily,—if not so accurately—the length of flashes in a coast-wise light as the duration of tones in a siren. The qualitative content is indifferent, and the variety of organic adjustments is as great as the number of senses which may be specifically involved. The essential point of the matter lies, not in the quality of the sensations or character of mechanism involved, but in the phenomena of general attentive adjustment common to all these processes alike. The root of the matter is reached by Titchener when he says: "When we try to discover by introspection what means we have used for our comparison of two durations of this third kind (one-half to three seconds), we find that strain intensities have played a great part in the formation of the judgment. The strain sensations come 1, from the expectant attitude of the whole body, and 2, from the adjustment of the sense-organ to the stimuli which limit the intervals to be compared. We estimate duration in terms of intensity: the more intensive the

strain, the longer must the interval have been; the less the strain, the shorter the time." [1]

The process of rhythmic integration is fundamentally involved not only in the estimation of relative duration in time intervals, but also in the numerical apprehension of serial impressions beyond very simple groups. Our immediate apprehension of number in temporal series is exceedingly weak, and extends at most to groups of half a dozen members. If the rate of succession be sufficiently low counting may be employed, and there is then no limit to the number of impressions of which one may keep tally; but this is in no sense the apprehension of a series. Each impression is perceived and named separately, and the process involves, in addition to this, only a memorizing of the final name uttered,—an ordinal term which becomes a symbol for the sum of the whole series.

The apprehension of a serial group is wholly unlike this. We can grasp only those series of impressions which are either so simple or so highly co-ordinated as to have a distinct form for our consciousness. Simple groups which are so characterized extend to four or five, possibly half a dozen individuals. Beyond this we fall back upon the process of rhythmization, the result of which is to extend such figuration to larger and larger series. We identify twenty-five impressions as we identify five; when the series is increased beyond the limits of apprehension as a group of individual elements we can estimate its number only when the conditions are such as to allow of the substitution of groups for elements as units in the process of apperception. What we recognize is not a larger number of units but a like number of units of a qualitatively different kind. They are such as we call "three-beat," or "five-beat," or "two-fours-beat" groups. The identification of the unit-group in such a case is as immediate and secure as the recognition of simple beats, or elements of any kind. The naming of the whole series as "ten," or "twenty-five" or "forty" strokes, is a secondary interpretation of the significance of the immediate apprehension. The form of the "twenty-experience" or the "forty-experience" is recognized as is that of any rhythmical sequence, and subsequent analysis alone translates that qualitative series into numerical values. Without this rhythmical emphasis and grouping such estimation would be absolutely impossible. The scope of this temporal consciousness depends upon the complexity of the units which enter into it. "Forty strokes might (then) be remembered as a whole, and identified without error when repeated, provided the mind grasped them in five sub-groups of eight, or in eight sub-groups of five strokes

[1] An Outline of Psychology, Cap. IV, p. 87.

each. When no grouping of the strokes beyond making *couples* of them by the attention was allowed—and practically it was found impossible not to group them in at least this simplest of all ways—sixteen was the largest number that could be clearly apprehended as a whole."[1] The particular number-groups apprehended with the greatest ease are those most readily subdivisible into rhythmical units; the most difficult are the prime numbers. "Series of 4, 6, 8, 16 were more easily identified than series of 10, 12, 14, 18. The latter could hardly be clearly grasped at all. Among odd numbers, 3, 5, 7, were the series easiest caught; next, 9, 15; hardest of all, 11 and 13; and 17 was impossible to apprehend."[2]

Such auditory series cannot be grasped at all if their succession falls below a certain rate, for beyond this limit the human consciousness has no capacity for rhythmical integrations of its impressions. When their succession rises above a certain other superior limit the numerical apprehension of the series of impressions again becomes confused, for while the rhythmic form still persists, the number of elements which are crowded into each simple group can no longer be discriminated. The range of rates within which such rhythmic integration is manifested in combination with clear discrimination of constituent sounds lies between two seconds and one-tenth of a second. The most favorable rate appears to be slightly more rapid than that instinctively adopted in free rhythmical tapping. This is due, I believe, to a difference in the mechanism of accompaniment in the two cases. The muscle system employed in beating out a rhythm with the finger presents a greater inertia than is involved in accompanying a sensory series by motor discharges which affect only certain parts of the vocal apparatus.

The limits of our capacity for estimating temporally extended periods or numerical series are to be looked for in the physiological laws which condition motor discharges on the one side, and make it possible or impossible for us to imitate the objective series by a system of organic strains; and on the other hand, in the limits placed upon our discrimination of refined experiences of strain due to perception-reflexes taking place in some part of the bodily organism.

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[1] Dietze, summed by James: Psychology, I, Cap. XV, p. 613.
[2] *Op. cit.*, p. 613.